EPTD DISCUSSION PAPER NO. 4

Environment and Production Technology Division

WATER MARKETS IN PAKISTAN: PARTICIPATION AND PRODUCTIVITY

Ruth Meinzen-Dick and Martha Sullins

International Food Policy Research Institute
1200 Seventeenth Street, N.W.
Washington, D.C. 20036-3006 U.S.A.

September 1994

ACKNOWLEDGMENTS

Research completed under USAID to Pakistan Grant Number 391-0492-G-00-1791-00 for the Ministry of Food and Agriculture, Government of Pakistan.

Special thanks are due to Naeem Sarwar and Khalid Saifullah for collecting additional data for this study, and to Manzoor Gill, Jafar Raza, Behjat Hojjati, and Sumiter Broca for assistance in analysis. Sohail Malik and Zakir Rana provided valuable comments and insight, in addition to much assistance in arranging for the data collection. Pierre Strosser collaborated extensively in identifying the important issues to be addressed with regard to water markets in Pakistan, and shared detailed field data used for comparison in this paper. Dr. Bashir Ahmed of Agricultural University, Faisalabad, also provided useful comments and access to National Input Output Survey data used for comparative purposes. Steve Vosti, Peter Hazell, Mark Svendsen, and Mark Rosegrant commented on a draft of the paper. Responsibility for any errors rests with the authors.

ABSTRACT

Water markets provide one of the most promising institutional mechanisms for increasing access to irrigation from groundwater, particularly for tenants and small farmers. While water markets are found in all provinces of Pakistan, they are most prevalent in canal irrigated areas of Punjab and in NWFP. This study reviews the emerging literature on water markets and uses farm-level survey data to examine the performance of groundwater markets, with particular emphasis on Faisalabad District in Punjab and Dir District in NWFP.

Findings indicate that, while large landowners are more likely to own tubewells and pumps, smaller landowners and tenants are more likely to rely on purchases from other farmers' tubewells for access to groundwater. The distance over which water can be transported provides a limitation to water market sales, but lined watercourses increase the distance over which tubewell water can be sold. Contractual arrangements for water in the IFPRI study areas of Faisalabad and Dir districts include hourly charges, buyer providing the fuel plus a fee for wear and tear, and sharecropping for water.

While all types of irrigation--canal, purchased groundwater, and own tubewell water--are shown to increase yields of wheat, groundwater has a higher impact than canal water, and water from own tubewells, which provides farmers with the greatest degree of control, has a greater effect on yields than purchased groundwater. Unreliability of access to purchased tubewell water was a problem for over half of water buyers in the study areas. This analysis indicates that purchasers are more likely to have unreliable access to groundwater if they buy water from small-capacity, electric-powered tubewells, if they are young and own little or no land.

Policy measures to improve access to and reliability of groundwater through water markets include increasing the density of tubewells, especially by assisting small farmers to purchase tubewells; lining water delivery channels; and providing more reliable electrical power supply to rural areas. Further research is needed on how water markets work in less favorable environments, such as those with salinity, waterlogging, or falling water tables, and to identify policy interventions that are appropriate under each set of circumstances.

CONTENTS

WATER MARKETS IN PAKISTAN: PARICIPATION AND PRODUCTIVITY

Ruth Meinzen-Dick[1] **and Martha Sullins**[***2]

1. INTRODUCTION

Irrigation plays a key role in Pakistan's strategy for increasing agricultural productivity. Surface irrigation has allowed the extension of cultivation into areas and seasons which lack sufficient rainfall for agriculture, and raised yields above what is possible under rainfed cultivation. Groundwater irrigation is increasingly important in improving production, either alone or in conjunction with surface irrigation.

Access to water in public irrigation systems (surface canals and public tubewells) is tied to ownership of land in the command area. This land ownership entitles the farmer to a fixed turn of irrigation flow during a rotation cycle, to be used only on that land. The rigidity of this system limits the productivity of surface irrigation and public tubewells, a limitation which is especially apparent in comparison with privately-managed groundwater irrigation, where farmers have more control of water timings (see Renfro and Sparling 1986).

Access to privately-managed groundwater irrigation is dependent on investment in wells and pumping devices. To the extent that large and wealthy farmers are most likely to own tubewells and small or poor farmers are unable to make the necessary

[1] Research Fellow, Environment and Production Technology Division, International Food Policy Research Institute.

[2] Former Senior Research Assistant, Environment and Production Technology Division, International Food Policy Research Institute.

investment, the latter may be excluded from the benefits of highly productive groundwater resources. On the other hand, widespread private ownership leads to over-investment in wells and pumpsets, particularly where holdings are small or fragmented. Institutional arrangements are needed to spread access to groundwater to other farmers, and to increase agricultural productivity and equity of irrigation water resources.

Water markets, in which farmers buy and sell irrigation water, provide one of the most promising institutional mechanisms for increasing access to irrigation with private groundwater, for providing vertical drainage, and for increasing the efficiency of water use in irrigation systems (see Rosegrant and Binswanger 1992). While such markets are not formalized or officially recognized, the sale of water from private tubewells is a growing form of water allocation. The sale and purchase of public canal water supplies, though legally prohibited under the Canal and Drainage Act, is another type of private water market transaction which takes place in Pakistan. These are, however, much less common than tubewell water sales.[1]

This paper examines the nature and operation of groundwater markets in Pakistan. It deals with the extent of water market development, who participates, the nature of transactions, the impact on productivity of irrigated agriculture, and the reliability of purchased irrigation services, with particular reference to Faisalabad District

[1] In the IFPRI sample, only 2 farmers reported purchasing canal water, compared to 74 purchasers and 10 sellers of tubewell water. A WAPDA (1990) study of water trading and sale practices in 100 water-courses found 2-3 times as many farmers involved in sale of water from private tubewells as from public (canal and tubewell) sources. The difference in amount of water sold was even more dramatic:

	Buyers		Sellers	
	Number	Total hours	Number	Total hours
Public sources	30	161	21	180
Private tubewells	107	4,635	44	22,979

in Punjab and Dir District in NWFP. The final section suggests policy instruments for extending water markets and improving their performance.

BACKGROUND

Irrigation provides crucial water for agricultural production on over 80 percent of the gross cropped area in Pakistan. Most of this irrigation comes through public canal systems, which, according to official reports, deliver surface water to approximately 70 percent of the irrigated area. However, throughout the 1970s and 1980s groundwater irrigation has been the most rapidly-growing source of irrigation: it now serves approximately 25 percent of the irrigated area, and provides over 36 percent of the irrigation water available at the farm gate (Pakistan: Ministry of Food, Agriculture and Cooperatives 1991; Rana and Shafiq-ur-Rehman n.d.). Groundwater has become a crucial input, both as a sole source of irrigation and as a supplement to surface irrigation in canal irrigation commands.

From the mid-1950s to 1980 public tubewells provided the primary source of groundwater irrigation development in Pakistan, under the Salinity Control and Reclamation Program (SCARP). According to the World Bank (1984:i): "The Government of Pakistan opted for public control of an extensive groundwater pumpage program based on the rationale that this arrangement would enable the Government to meet multiple groundwater objectives in an efficient and equitable manner." These objectives included:

1. providing vertical drainage to control waterlogging and salinity problems, especially in saline groundwater areas.
2. increasing cropping intensities and agricultural production.

3. capitalizing on the economies of scale in pumping technology. By providing water to a larger area than that controlled by single farmers, public tubewells could use larger pumps which are, in theory at least, more efficient.
4. reducing inequity in access to groundwater, by serving farmers with all sizes of holdings, regardless of financial resources for investment.

In practice, institutional problems as well as technical difficulties resulted in disappointing performance of public tubewells. Rising operation and maintenance expenses for public tubewells (which consumed 60 percent more than the entire national budget for canal operation and maintenance in 1983/84; see Aklilu and Hussain 1992:29), in conjunction with the poor performance of public tubewells in terms of timeliness and reliability of irrigation supplies, led the government to devolve responsibility for groundwater irrigation development from the public to the private sector. The first two policies adopted in Pakistan's Revised Action Plan for Irrigated Agriculture (WAPDA 1982: 16) were:

Recommendation 1: Future Development of Usable Groundwater should be entrusted to Private Sector, . . .

Recommendation 2: Present SCARP Tubewells in the Usable Groundwater Areas should be phased out and Replaced by Private Tubewells.

Pakistan's experience suggests that private tubewell development can fulfill the objective of providing adequate vertical drainage, at least in areas of fresh groundwater (Chaudhry and Young 1990). By 1982, approximately 80 percent of total groundwater was extracted through 186,000 private tubewells, compared to 20 percent provided by

12,500 public tubewells (World Bank 1984).[2] Increases in cropping intensities and agricultural productivity are greater under private tubewell ownership, primarily because private tubewells are more reliable (Johnson 1989:15; World Bank 1984:29). The potential gains in technical efficiency derived from public tubewells using large-capacity pumps are offset, in practice, by frequent breakdowns and inadequate maintenance. Most private tubewells provide greater water use efficiency by more closely matching water deliveries to crop needs, instead of adhering to the rigid schedules of public tubewell deliveries. However, as the government closes public tubewells, the extent to which private groundwater development will benefit a large number of farmers and meet stated equity objectives remains an important question.

There is increasing interest throughout much of South Asia in water markets as a means of increasing access to and use of groundwater for irrigation.[3] Much of the literature on this subject is based on field studies conducted in India and Bangladesh. This paper reviews the issues identified in this literature, in order to set the stage for an empirical study of the performance of water markets in Pakistan.

[2] The large majority of tubewell development has taken place in Punjab. In 1989/90, 88 percent of the private and 65 percent of the public tubewells of Pakistan were located in that province (Pakistan, Ministry of Food, Agriculture and Cooperatives 1991:194).

[3] Water markets were a major topic in the World Bank Colloquium on How to Reach the Poor Through Groundwater, in Washington DC, April 12-14, 1989.

Although water sales from private wells are a longstanding practice, these informal arrangements have only recently been recognized and empirically examined (Chambers, Saxena and Shah 1989:100-101).[4] In most cases in South Asia, water sellers are farmers who sell surplus water after meeting the needs of their own fields. In Gujarat State in India, where water markets are highly developed, individuals and even private water companies are investing in wells primarily to sell water to others. Tubewell water sales have become a profitable enterprise for small farmers in Uttar Pradesh in India (Shankar 1992a) and even for the landless under the PROSHIKA program in Bangladesh (Wood and Palmer-Jones 1990).

In Pakistan, water markets are reported in all provinces, but are most active in Punjab, where the greatest groundwater development has taken place. By 1975, over 30 percent of tubewell owners in Pakistan reported selling water, but the fraction of water sold was very small (World Bank 1984:35). A study by Pakistan's Water and Power Development Authority in canal command areas of Punjab, Sindh, and NWFP found water sales in 43 of 100 watercourses (WAPDA 1990; see also Bajwa and Ahmad 1991). Sims' (1988) micro-level study in canal-irrigated villages in the Punjab found that approximately one-third of farmers purchased groundwater from neighbors, while 29 percent owned tubewells.

The potential advantages gained from groundwater market development lie in improving utilization of tubewell capacity, increasing access to irrigation water supplies

[4] There are numerous anecdotal reports and a growing number of studies of private water sales in Uttar Pradesh, Haryana, Punjab, Bihar, West Bengal, Orissa, and Andhra Pradesh in India (Shankar 1992a, b; Pant 1991a, b; Kolavalli and Atheeq 1990; Kolavalli, Naik and Kalro 1992; Kolavalli, Kalro and Asopa 1989; Saleth 1991; Shah and Raju 1988). Perhaps the most highly-developed private water markets in India are found in Gujarat state, where farmers invest in wells and underground networks of pipes for water deliveries (Shah 1985; Kolavalli and Chicoine 1989).

(especially among farmers with small or fragmented holdings), and lowering water tables in areas of waterlogging (see Chambers, Saxena and Shah 1989; Chaudhry and Young 1990). By providing water to other farmers, tubewell owners can use a higher proportion of their well capacity than they would otherwise use on their own holdings. The availability of hired tubewell services reduces the need for other farmers to install their own wells. Because water markets increase the use of installed pumping capacity, they can improve the economic efficiency of private tubewell irrigation.

Private well ownership tends to be concentrated among larger or wealthier farmers because of their ability to mobilize the necessary resources, including personal finances, credit, and government connections for electricity supplies (Chambers, Saxena and Shah 1989; Johnson 1989; Chaudhry 1990). According to the World Bank (1984:35), 70 percent of tubewells are owned by farmers with over 12.5 acres, and half of all tubewells by farmers with over 25 acres, which seems "to point toward an adverse effect of private tubewells on income distribution within agriculture." Water markets make it possible for those without wells to use groundwater for irrigation.[5] The opportunity to sell groundwater can make it profitable for farmers to invest in wells even if their own holdings are too small to use the full pumping capacity (see Shankar 1992b). Dhawan concludes:

> the thrust of empirical research on groundwater markets, both in India and Bangladesh, has been to underscore the superiority of the institution of groundwater markets over the public tubewell system in catering to the irrigation needs of small and marginal farmers (1991:2).

[5] In examining inequality of irrigation distribution, Gill and Sampath (1992) note the effect of water trading and sales, especially in Rabi season, in promoting equity.

Shah (1991) argues that the expansion of irrigation through water markets provides increases in cropping intensity and the demand for agricultural labor, which ultimately benefit the landless and those who rely on wage labor for household income. Increased employment opportunity is one of the biggest advantages for landless members of pump groups in Bangladesh (Wood and Palmer-Jones 1990).

Other researchers on water markets voice concern regarding who appropriates the gains from irrigation (e.g. Pant 1991b). Groundwater is an open access resource, but ownership of wells and pumps is required to extract the water. The prospect of exploitative "water lords" has been raised, especially where control over water through well ownership reinforces inequality based on land and other assets (e.g. Barah 1992). Shah (1991) suggests that well owners extracting monopoly rents from the sale of water is most likely to be problematic where the markets are not competitive. Since water transactions are restricted by topography and the distance between source and field, market competition is more difficult to achieve. However, Shah (1991) suggests that the availability of groundwater resources and alternative irrigation supplies (especially canal water), a high density of wells, and the presence of lined conveyance structures can reduce the sellers' monopoly power and hence the price of water.[6]

Empirical research and anecdotal evidence indicate a variety of contract forms and wide range of prices in water markets. Buyers may be required to provide labor, fuel, or a share of the crop, though the tendency is to move toward a cash charge per hour of water supplied as water markets develop (Chaudhry 1990, Shah 1991).

---

[6] Pant (1991b: 277) also observed that the relative social and economic position of buyers and sellers affects water rates. In Orissa State, India, small farmers selling water to large landowners charged less than nearby large farmers selling to small landowners.

Research has shown that the energy pricing structure has a major influence on the price of water in private groundwater markets (Shah 1985, 1991). In India, a flat monthly rate based on the horsepower of the engine is associated with a much lower water price than a unit charge based on electricity consumption. With the flat rate power tariff, the marginal cost of pumping is dramatically reduced, and therefore well-owners maximize their profits by pumping and selling as much water as possible (within the limitations of groundwater and power availability). Water from diesel wells is consistently sold at a higher rate than water from electric wells of similar capacity because of the higher energy, capital, and maintenance costs.

Kolavalli (1989) notes that transactions are not impersonal, but are part of multi-stranded linkages in which buyers may give preference to relatives or those with whom they have other relationships, either through lower water rates or priority for service. This may be a way of dealing with high transactions costs for water sellers, particularly where water is provided on credit (see also Bardhan 1984). Detailed observations on the relationships between buyer and seller and their effects on price and reliability of irrigation services are difficult to collect, and therefore have not been carefully examined in previous studies.

While several studies of water markets have dealt with the price of water (e.g. Kolavalli and Atheeq 1990; Shah 1989), there has been less analysis of the reliability of purchased private irrigation services and its impact on productivity. Chambers, Saxena and Shah (1989) cite farmers' preference for purchased irrigation water above canal supplies as evidence of quality of service, but admit the difficulty of estimating adequacy, reliability, and other indicators. Freeman, Lowdermilk and Early (1978) and Renfro

(1982) studied water trading and sales in Pakistan as a means of increasing farmers' control over irrigation supplies. The former used yields as a proxy indicator of quality of irrigation services; the latter used data on water and cash input use, cropping intensity, and gross income per unit area. Both studies found that, while water purchases increased productivity over canal irrigation alone, they did not have as great an effect as tubewell ownership because tubewell ownership provided a higher degree of control.

The following sections of this paper use empirical data to address both productivity and equity aspects of water markets in rural Pakistan. Data on reliability of irrigation service and on agricultural production allow us to deal with the impact of water markets in greater detail than previous studies. Household surveys on various aspects of agricultural production and rural poverty conducted by the International Food Policy Research Institute (IFPRI) in Faisalabad, Attock, Dir, and Badin Districts during 1990 to 1992 provide the basis for much of the analysis. While the latter three districts were selected to represent the poorest infrastructure development in Punjab, NWFP and Sindh provinces, Faisalabad was included to represent a leading agricultural district (see Alderman and Garcia, 1991). Data on household assets and agricultural production are available from 1986 to 1992, but the last full survey round, covering the 1990-91 agricultural year, provides the greatest detail on agricultural production and irrigation, and will therefore be used in this paper. Plot-level data on soil characteristics from all sample farmers are also available from 1992. A re-survey of all tubewell owners and households participating in water markets, conducted in 1992, provides detail on these transactions and on reliability of water markets. While the study attempts to link findings from the study areas to patterns of water markets indicated in other, more nationally representative studies, the findings are largely based on Faisalabad and Dir Districts.

2. WHO PARTICIPATES IN WATER MARKETS?

Water markets are most prevalent in the Punjab and Northwest Frontier Provinces of Pakistan, where groundwater irrigation is most developed. Punjab contains the highest number of well-owners who sell water, as well as the highest number of private wells. However, in NWFP a higher proportion of well-owners are involved in water markets: according to NESPAK (1991) data, 25 percent of sample well-owners reported selling water in NWFP, compared to 22 percent in Punjab, 3.5 percent in Sindh, and 2.5 percent in Baluchistan.[7]

In the IFPRI study, water markets were found only in Faisalabad District of Punjab and Dir District of NWFP. Attock District of Punjab is a barani (rainfed) area, and no Attock farmers in our sample owned or used tubewells. The study villages in Badin District of Sindh are largely underlain by saline groundwater aquifers, which pose a serious constraint to groundwater irrigation and water market development. Only one of the sample farmers from Badin owns a tubewell, but does not sell water from it; none reported buying groundwater.

[7] Provincial figures reported in the NESPAK (1991) final report are a simple average percentage of well owners selling water across all districts. The percentages reported here are a weighted average of percentage selling, with the number of tubewells in each district as the weights.

The study areas in Faisalabad District lie within the command area of the Rakh, Jhang, and Gugera Branches of the Lower Chenab Canal, with a relatively flat terrain. Canals provide the sole source of irrigation to 53 percent of the cultivated area in the Division (including Jhang and Toba Tek Singh Districts), with groundwater irrigating an additional 13 percent of the area, and conjunctive use of surface and groundwater on 31 percent of the area (Punjab Bureau of Statistics 1988). Groundwater use in the district is less than recharge, but there are some problems with groundwater salinity. Annual rainfall is under 500 millimeters, so cultivation is heavily dependent on irrigation. The major crops grown in Faisalabad are wheat, sugarcane, cotton, rice, and maize. Dir district has relatively hilly terrain. With higher annual rainfall (averaging 1364 millimeters), the area is less dependent on irrigation. The main sources of irrigation are small-scale surface systems, with some tubewells. The major crops are wheat, tomato, onion, and maize.

The pattern of water market participation found in the IFPRI study, with greatest activity in canal-irrigated areas of Punjab and in NWFP, is largely borne out by data from the National Input Output Survey of Major Crops, which interviewed 1700 farmers distributed across all agroecological zones in Pakistan,[8] with the exception of Baluchistan. Table 1 indicates that the highest proportion of farmers relying on purchased groundwater was found in the cotton/wheat zone of Punjab (Sahiwal, Bahawalnagar, Bahawalpur, R.Y. Khan, and Multan/Vehari districts), where over a third of all farmers buy tubewell water. The mixed cropping zone of Punjab, which includes Faisalabad District, had the second highest proportion of tubewell water buyers, with

[8] For details on the classification of agroecological zones, see Pinkney (1989).

21.8 percent. Although 16 percent of farmers in the barani zone of Punjab, which includes Attock, purchase groundwater and 36 percent own tubewells, tubewell use is concentrated in Jhelum District, and is very low in Attock District itself (Punjab, Bureau of Statistics 1988:53).

Table 1--Type of irrigation and access to tubewell water by agroecological zone

	Punjab Zones					Sindh Zones		NWFP Zone	
	Rice/ Wheat	Mixed	Cotton/ Wheat	Low Intensity	Barani	Cotton/ Wheat	Rice/ Other	Except DI Khan	Total
Unirrigated	3 (0.7)	0 (0.0)	4 (1.00)	0 (0.0)	24 (48.0)	0 (0.0)	0 (0.0)	71 (51.4)	102 (6.2)
Public irrigation sources only	108 (26.5)	27 (17.3)	106 (27.4)	69 (30.4)	0 (0.0)	119 (85.0)	136 (97.1)	59 (42.8)	624 (37.9)
Purchased tubewell water only	39 (9.6)	1 (0.6)	16 (4.1)	14 (6.2)	8 (16.0)	3 (2.1)	0 (0.0)	5 (3.6)	86 (5.2)
Canal and purchased tubewell water	19 (4.7)	33 (21.2)	121 (31.3)	54 (23.8)	0 (0.0)	1 (0.7)	1 (0.7)	2 (1.4)	231 (14.0)
Own tubewell water only	128 (31.4)	12 (7.7)	30 (7.8)	13 (5.7)	18 (36.0)	1 (0.7)	0 (0.0)	1 (0.7)	203 (12.3)
Canal and own tubewell water	110 (27.0)	83 (53.2)	110 (28.4)	77 (33.9)	0 (0.0)	16 (11.4)	3 (2.1)	0 (0.0)	399 (24.3)
Total sample size	407 (24.7)	156 (9.5)	387 (23.5)	227 (13.8)	50 (3.0)	140 (8.5)	140 (8.5)	138 (8.4)	1645 (100.0)

Source: Calculated from data in National Input Output Survey of Major Crops, collected by Agricultural University, Faisalabad. Agroecological zones defined as in Pinckney, T. C. *The demand for public storage of wheat in Pakistan*. IFPRI Research Report 77. (Washington, D.C.: International Food Policy Research Institute, 1989).
Note: Figures in parentheses are percentage of farmers in zone.
[a]DI Khan District of NWFP is included in Punjab low-intensity zone.

Less than 3 percent of farmers use any groundwater in either of the zones in Sindh. Of 138 farmers interviewed in the NWFP zone, only 5 percent reported purchasing water from tubewells.

The extent of water market participation among IFPRI sample farmers in Faisalabad and Dir districts is indicated in Table 2. Nearly half of the sample farmers in Faisalabad District purchase tubewell water, more than twice the number who own tubewells. Of the 22 sample farmers who own tubewells in Faisalabad, only 5 reported selling tubewell water. In Dir, where groundwater irrigation is less prevalent, nine percent of all sample farmers purchase water, approximately the same proportion who own tubewells, but twice the number who sell tubewell water. Water markets are most pervasive in Faisalabad, where groundwater purchasers or sellers were found in all six study villages (Table 3). Within the villages, participation rates ranged from 0 to 16 percent of farmers (0 to 100 percent of tubewell owners) selling water, and 0 to 81 percent of farmers purchasing water. Although all villages in Faisalabad fall within the command area of public canal irrigation systems, the watercourses in Jaranwala receive almost no surface water. Thus many of the farmers in Jaranwala have invested in wells, often jointly with other farmers, giving it a significantly higher proportion of well owners (75 percent of sample farmers) than other villages.

Only five of eleven study villages in Dir had any groundwater use among sample farmers, and groundwater markets were reported in three of those five

villages (Table 4). The water market is most active in Katigram, where more than one-fourth of the farmers own tubewells, and nearly all well owners sell water.

Table 2--Sample farmer participation in tubewell water market in Faisalabad and Dir Districts, 1992

	District		
	Faisalabad	Dir	Total
Tubewell owner	22 (22.2)	7 (7.9)	29 (15.4)
Tubewell water seller	5 (5.1)	4 (4.5)	9 (4.8)
Tubewell water buyer	49 (49.5)	8 (9.0)	57 (30.3)
Total sample size	99	89	188

Source: IFPRI survey data, 1992.
Note: Figures in parentheses are percentage of sample farmers in the district.

Table 3--Water market participation among IFPRI sample farmers in Faisalabad District, by village, 1992

	Village						
	Saddoana	Singpura	Jaranwala Chak	Gojra Subadarwala	Khalisabad	Sumundri	Total
Tubewell owner	0 (0.0)	1 (16.7)	15 (75.0)	1 (9.1)	4 (18.2)	1 (5.3)	22 (22.2)
Tubewell water seller	0 (0.0)	1 (16.7)	3 (15.0)	0 (0.0)	0 (0.0)	1 (5.3)	5 (5.1)
Tubewell water buyer	15 (71.4)	4 (66.7)	5 (25.0)	7 (63.6)	18 (81.8)	0 (0.0)	45 (45.5)
Total sample size	21	6	20	11	22	19	99

Source: IFPRI survey data 1992.
Note: Figures in parentheses are percentage of sample farmers in the village.

TUBEWELL OWNERS

What are the characteristics of tubewell owners and water purchasers? Table 5 presents a logistic regression (logit) model used to examine tubewell ownership among sample farmers in Faisalabad and Dir districts. The logit technique allows us to examine the effect of a number of variables on the underlying probability of a dichotomous dependent variable, such as the probability of owning a tubewell. In this model, land ownership, age of head of household, whether a household has a member who has worked or is working abroad, and dummy variables for Jaranwala village and Dir district (areas with less access to canal irrigation) are hypothesized to influence the probability of owning a tubewell. The dummy variables are proxy indicators for availability of alternative water supply. Other indicators of water supply, such as position of farm relative to canal systems and discharge in the watercourse, might refine the model, but are difficult to quantify and measure. Household wealth or income are not included in the model because it is likely that tubewell ownership has contributed to wealth or income, rather than the reverse. Similarly, factors such as cropping pattern, which influences demand for tubewell water, are not included because no indicator is available for farmers' desired cropping pattern, and availability of tubewell water has a stronger influence on cropping pattern than actual cropping pattern has on availability of tubewell water.

Table 4--Water market participation among IFPRI sample farmers in Dir District, by village, 1992

	Village						
	Katigram	Batan	Shah Alam Baba	Khanpur	Kamangara	6 Other Villages	Total
Tubewell owner	5 (27.8)	0 (0.0)	1 (14.3)	0 (0.0)	1 (20.0)	0 (0.0)	7 (7.9)
Tubewell water seller	4 (22.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	4 (4.5)
Tubewell water buyer	1 (5.6)	3 (25.0)	0 (0.0)	4 (21.1)	0 (0.0)	0 (0.0)	8 (9.0)
Total sample size	18	12	7	19	5	28	89

Source: IFPRI survey data, 1992.
Note: Figures in parentheses are percentage of sample farmers in the village.

Table 5--Results of logistic regression model for tubewell ownership

Independent Variables	Units	Coefficient	T Ratio	Wald Statistic
Size of land ownership	acres	.122 **	4.03	16.24
Age of head of household	years	.051 **	2.34	5.48
Relative abroad	dummy	1.668 **	2.15	4.63
Jaranwala village	dummy	4.458 **	5.41	29.32
Dir district	dummy	.036	.05	.00
Constant	-6.829 **	-4.35	18.90	

Model Chi-Square = 66.9 ** with 5 degrees of freedom
Number of observations = 182.0

Classification Table for Tubewell Ownership

Observed	Predicted NOT OWNER	Predicted OWNER	Percent Correct
NOT OWNER	147	7	95.4
OWNER	12	16	57.1
		Overall	89.6

Source: IFPRI survey data, 1991/92.
** Significant at 5 percent probability level
* Significant at 10 percent probability level

Results of this model indicate that land ownership has a strong positive effect on well ownership, implying that households owning more land are more likely to own wells. The age of head of household has a significant positive effect on well ownership, perhaps because farmers invest in tubewells as the household becomes established. Households with a member currently working abroad or returned from abroad are also significantly more likely to own wells. This seems to indicate that remittances are a source of financing for tubewell investment.[9] The dummy variable for Jaranwala village has a large and significant coefficient. As noted above, the lack of alternative canal irrigation supplies has pushed these farmers to purchase tubewells, and joint investment has enabled even small farmers in this village to own at least a partial share of a well. The pattern of well ownership in Dir district, however, is not significantly different from that of Faisalabad district. This model correctly predicts the well ownership status of 90 percent of all cases.

[9] The reverse direction of causality--that income derived from tubewell ownership has financed international migration--is unlikely. Adams' (1992) study of migration among households in the IFPRI sample found that households with less than an acre of irrigated land were most likely to migrate.

Although small holding size is not an insurmountable obstacle to well ownership (as demonstrated by a high proportion of joint well owners with small holdings in Jaranwala village), it is a constraint to widespread tubewell ownership. Tenants, especially those with no land of their own, are at a disadvantage in tubewell ownership because they do not have secure enough rights to land on which to install a tubewell, and are likely to face credit constraints for tubewell investment (see Malik, Broca and Gill 1992). In the survey on water markets, over 60 percent of groundwater purchasers cited the expense of purchasing a tubewell as the reason why they did not have their own wells, but 25 percent cited a lack of land ownership or too small a holding size as the reason for not investing in a well (Table 6). Groundwater quality problems also prevent farmers from installing their own wells. Water markets meet a need for water among those who have too little land, cannot afford tubewells, or find the investment not worthwhile, and those who have problems with the groundwater quality on their own land.

TUBEWELL WATER PURCHASERS

A logistic regression model, similar to that for tubewell ownership, has been calculated to identify factors which predict who purchased tubewell water during rabi and kharif of 1991-92 (Table 7).[10] Since remittances are less likely to have an impact on water purchases than on investment in tubewells, the variable for relatives abroad is omitted from this model, but a variable for season is added to see if there is a significant difference between rabi and kharif irrigation purchases. As in the model for tubewell

[10] Because of the small number of tubewell owners in the sample, it is not possible to develop a model to predict which tubewell owners sell water.

ownership, cropping patterns are not included because they are determined largely by the availability of water. The location of fields relative to the canal system and to tubewells whose owners are willing to sell, along with ground- water quality are likely to affect water purchases, but these factors are not included because the data are unavailable.[11]

Table 6--Water buyers' reasons for not owning tubewells

	District		
	Faisalabad	Dir	Total
Too expensive	40	14	54
	(54.1)	(93.3)	(60.7)
Holding too small	11	0	11
	(14.9)	(0.0)	(12.4)
Not landowner	12	0	12
	(16.2)	(0.0)	(13.5)
Land not near canal	1	0	1
	(1.4)	(0.0)	(1.1)
Groundwater quality	6	1	7
	(8.2)	(6.6)	(7.8)
Only buy when own TW broken	3	0	3
	(4.1)	(0.0)	(3.4)
Purchase as supplement only	1	0	1
	(1.4)	(0.0)	(1.1)
Total number of water buyers	74	15	89

Source: IFPRI survey data, 1992.
Note: Figures in parentheses are percentage of water buyers.

[11] Tubewell ownership was not included in the model because of the high multicollinearity between land ownership and tubewell ownership. Similarly, operational holding size was not included because it is highly correlated with land ownership. An alternative specification of the model, with operational holding instead of land ownership, did not show a significant effect of holding size on water purchases.

Table 7--Results of logistic regression model for tubewell water purchase

Independent Variables	Units	Coefficient	T Ratio	Wald Statistic
Size of land ownership	acres	- .039 **	-2.28	5.22
Age of head of household	years	- .031 **	-3.30	10.87
Season	dummy	- .355	-1.24	1.54
Jaranwala village	dummy	-1.398 **	-3.38	11.46
Dir district	dummy	-3.262 **	-8.15	66.50
Constant		2.250 **	3.98	15.82

Model Chi-Square = 118.4 ** with 5 degrees of freedom
Number of observations = 352.0

Classification Table for Tubewell Ownership

	Predicted NOT BUYING	Percent BUYING	Correct
Observed			
NOT BUYING	221	31	87.7
BUYING	36	64	64.0
		Overall	81.0

Source: IFPRI survey data, 1990-1992.
** Significant at 5 percent probability level
* Significant at 10 percent probability level

This model shows that, whereas the size of land ownership and the age of household head have a strong positive effect on tubewell ownership, these variables have a significant negative effect on water purchases.[12] Thus younger households with less land are more likely to purchase groundwater than older households owning substantial amounts of land. Tenants are likely to be dependent on other households' tubewells, as well as other households' land, for their cultivation. Farmers in Dir are significantly less likely to purchase groundwater than those in Faisalabad, in part because of the lower availability of tubewells in Dir.[13] Farmers in Jaranwala are also significantly less likely to purchase water. In this village joint ownership, rather than water markets, provides small farmers with access to groundwater. Because alternative sources of irrigation are not available, farmers in that village seek to assure themselves of access to groundwater by investing in wells rather than depending on groundwater purchases. The season does not have a significant effect on water purchases: 30 percent of farmers reported purchasing irrigation in kharif, compared to 25 percent in rabi.

Land ownership and age are indicators of overall status of farm households. Investment in tubewells are not made for prestige, but the status of households can enable them to mobilize the resources needed for tubewell investment, including financial resources and government assistance (such as electricity connections). Therefore, it is

---

[12] In a logit model for groundwater purchasing, using cross-sectional survey data from 5 states in India, Saleth (1991) also found a significant negative effect of farm size on likelihood of purchasing in 3 of 5 states. The other two states are characterized by very small and fragmented holdings and higher average rainfall. Thus the need for supplemental groundwater was less, and the larger farmers in those states were as likely to purchase groundwater as small farmers.

[13] The effect of number and density of tubewells in a village was tested in an alternate specification of the model. Tubewell density has a significant positive effect on the likelihood of water purchases, both in addition to the dummy variables for Dir and Jaranwala, and without the dummy variables included. The variable for tubewell density is not included in the final model because there are multicollinearity problems when it is included along with the dummy variables for location, and tubewell density does not explain as much as the two dummy variables.

not surprising that higher-status households are more likely to own wells, and lower-status households are more likely to rely on tubewell water purchases.[14] However, not only low-status households purchase water: 7 of 28 tubewell owners in the IFPRI sample also purchase water. Water purchases may provide a backup when a farmer's own well is not functioning, or may be used to irrigate land that cannot be served by a farmer's well. In several cases, farmers preferred buying water to operating their own wells because purchased water from electric-powered wells was cheaper than using their own tractor-powered tubewells.

Results of these model indicate that, whereas private tubewells are likely to be owned by large farmers, water markets improve equity of groundwater use by making water available to small landowners or tenants and younger households--those farmers who are least likely to own tubewells. In Faisalabad, where water markets are most active, they provide the only access to groundwater for approximately half of the farmers who own less than 12.5 acres.

[14] A comparable pattern of larger landowners owning wells and smaller landowners purchasing tubewell water, based on National Input Output Survey data from the Punjab mixed cropping zone, is shown in Appendix Table 1.

3. RELATIONSHIPS BETWEEN WATER BUYERS AND SELLERS

PHYSICAL RELATIONSHIPS

Water markets are not perfectly competitive markets in which buyers are free to choose among a number of sellers. In many areas there are not a large number of water sellers, and, under most conditions prevailing in Pakistan, tubewell irrigation water is not a commodity which can be transported far from the source to the area of application. Conveyance losses between the tubewell and the field restrict purchasers to buying from tubewells located in close proximity of their fields. The distance over which it is feasible and economically viable to transmit water depends on the soils, topography, and type of channel used to convey the water. In the IFPRI study, the average distance between the tubewell and purchasers' fields was 600 meters in Faisalabad District, and 180 meters in Dir, which has more undulating topography. Use of lined watercourses or field channels, which have lower transmission losses than unlined channels, increases the distance over which water can be transported. Ten of the thirteen cases in which the distance between source and fields was over 1000 meters used lined watercourses (including one case in which water travelled down 3 kilometers of lined watercourse between the well and field).

Lined canals and pipes ensure that water purchasers receive more of the water they pay for from the tubewell, and permit sales to a wider potential number of fields from each tubewell.[15] Thus, they go hand in hand with the development of competitive water markets. They allow purchasers to obtain water within a wider radius of their

[15] Underground pipes can even, to some extent, overcome topographic limitations to water sales, by enabling water to reach fields at a higher level than the tubewell.

fields, thereby increasing the number of potential suppliers. Shah and Raju (1988) report that as competitive water markets developed in Gujarat state, India, tubewell water sellers who wanted to maintain clients install lined conveyances to ensure that water reaches as many buyers as possible with low losses.

Despite these advantages of water markets, there has been little private investment in lining or pipes in the IFPRI sample areas. Four farmers reported using lined field channels to convey purchased tubewell water part of the way (though in two of these cases the lined field channels were only the first 20 meters from the tubewell). Three sellers used underground pipes, which have the lowest conveyance losses. Pukka (lined) watercourses are used more frequently than lined field channels or pipes because watercourse lining results from government and collective farmer investment, while lining field channels or installing pipes requires considerable private investment.

Farmers use watercourses for tubewell water despite the Canal and Drainage Act provision that all who do so are assessed the water rate for canal irrigation use. A NESPAK (1991) study suggests that this law restricts the sale of tubewell water, and recommends allowing farmers to use watercourses for tubewell water without charge to encourage water markets and the mixing of marginal-quality tubewell water with fresh canal water supplies. The Canal and Drainage Act further restricts transporting tubewell water by prohibiting farmers from carrying water across public watercourses. It may be worth lifting this restriction, provided the pipes or other structures used to carry the tubewell water do not block or erode the watercourse.

Renfro's (1982) study notes an association between private tubewells and collective activity among farmers, particularly with regard to watercourse lining.[16] Renfro and Sparling (1986:206) suggest the reason for this is that "Farmers with cooperative neighbors are more likely to invest in tubewells, and the presence of private tubewells gives farmers new reasons to cooperate with each other." However, this explanation omits the role of watercourse lining in reducing transmission losses of high-value groundwater. An alternative explanation is that, with tubewell use in general, and water market sales in particular, farmers recognize the value of canal lining and have greater incentive to reduce water losses. With lined watercourses, tubewell water can be conveyed over a greater distance between the well and fields, thus expanding the potential market from tubewells along the watercourse. Renfro and Sparling (1986:206) argue that watercourses with private tubewells are less in need of lining because they have additional sources of water. However, watercourse rehabilitation not only conserves canal water, but by reducing transmission losses of tubewell water, lining can also encourage the development of competitive water markets. Therefore, in areas where watercourse lining is to be done, it may be appropriate to give priority to lining watercourses with private tubewells as a means of fostering water markets.[17]

SOCIAL RELATIONSHIPS

Physical proximity is not the only relevant relationship which influences the development of competitive water markets. Social relationships between buyer and seller

[16] Under the On-Farm Water Management projects implemented by the Government of Pakistan with USAID and World Bank assistance, farmers are required to organize into Water Users' Associations in order to receive government assistance for watercourse improvement (see Byrnes 1992).

[17] Lining watercourses will also reduce groundwater recharge to some extent, and thus reduce availability of tubewell water. However, there will continue to be recharge from irrigated fields.

may also restrict the sale and purchase of groundwater if tubewell owners are only willing to sell to close relatives or those with whom they have other ties. This does not appear to be a problem in the IFPRI study areas. Only 22 percent of water market transactions in Faisalabad District were between close relatives. Approximately one third (37 percent) of transactions were between members of the same biradari, which represents a broader social grouping. Sale of tubewell water between kin is even more rare in Dir, where only 2 percent of transactions were between close relatives or biradari members. There, water market transactions were more likely to follow patron-client ties, with 37 percent of sales reported between landlord and sharecropper (compared to less than 1 percent in Faisalabad District).

As noted above, selling water to relatives is a means of controlling transactions costs and ensuring fee repayment. Relatives may also have the closest land holdings, due to inheritance patterns. However, transactions costs may be higher with relatives, either because of quarrels or difficulty in collecting payments. Shah (1992) hypothesizes that as water markets develop, they become de-personalized. This seems to have taken place in the study areas, because personal relationships neither restrict access to groundwater nor are shown to have a significant effect on the reliability of deliveries, as discussed below.

4. NATURE OF WATER MARKET CONTRACTS

A flat charge per hour of pumping is the most common form of water market contract in both Faisalabad and Dir districts (Table 8). This type of arrangement occurs under diesel, tractor, and electric-powered pumpsets. Water from diesel pumpsets in Jaranwala is commonly sold under an arrangement whereby the buyer supplies the diesel and motor oil for the pump, and pays an additional fee of Rs 4 to Rs 6 per hour to the well owner to cover the wear and tear on the engine. Sharecropping contracts for water are used under both diesel and electric tubewells in Dir.

Table 8--Water market contracts, by type of pump

	Type of Pump			
	Diesel	Tractor	Electric	Total
Faisalabad District				
Flat charge per hour	9	19	44	72
Buyer brings fuel	18	0	0	18
Share of crop	0	0	0	0
Total	27	19	44	90
Dir District				
Flat charge per hour	13	0	0	13
Buyer brings fuel	0	0	0	0
Share of crop	2	0	6	8
Total	15	0	6	21

Source: IFPRI survey data, 1992.
Note: Table includes number of sellers' and buyers' responses about type of contract.

Prices under the hourly charge system range from Rs 14 to Rs 80 per hour, depending on the pump type, capacity, and location (see Table 9). The higher price of water from tractor tubewells reflects the higher cost of operating this type of pump. The average price of water under the hourly charge system is approximately the same for diesel and electric tubewells, although the former are usually more expensive to operate. The average capacity of the electric tubewells is higher, though, so the cost per horsepower is lower for electric than diesel tubewells. The mean hourly cost of water to the purchasers from diesel tubewells is slightly higher under the buyer-brings-fuel system than under the flat hourly charge. Water sellers with diesel pumps are apparently only recovering their own costs under either type of contract.[18] The sellers' transactions costs in acquiring the fuel and operating or supervising the operations of the pump are presumably higher under the hourly charge contracts, but there may be an unwillingness to let some purchasers operate the pumps themselves under the buyer-brings-fuel system. Among IFPRI sample villages, the buyer-brings-fuel contract was only found in Jaranwala, where there is also a high incidence of joint ownership of wells. However, this type of contract is also reported in other areas with conjunctive canal and tubewell irrigation, such as in southern Punjab.

All water transactions under hourly charge contracts in Dir are found in Khanpur. The price is Rs 40 to 80 per hour, which is higher, on average, than in

Faisalabad. Several factors could account for the higher price in Khanpur: the well from which most farmers purchase is large-capacity, powered by a 113-horsepower truck engine, and therefore more expensive to operate.[19] Irrigation water is also more scarce in Dir than in Faisalabad, where canal water is more readily available and groundwater tables are generally higher. A final consideration may be that most water purchasers in Khanpur are buying water from their landlord, whereas that is only found in one case in Faisalabad.

---

[18] Unfortunately, much of the information on price of purchased tubewell water comes from water buyers, rather than from the sellers. There are thus not enough data on tubewell operations costs and water delivery rates to determine the profit margin for water sales or the exact price per unit water pumped.

[19] The price per horsepower is lower in Dir than Faisalabad, but this may be misleading because the relationship between horsepower and water delivery is not linear, particularly when comparing the pumpset powered by a truck engine with lower-horsepower engines designed for tubewells.

Table 9--Average cost of tubewell water, by type of pump and contract

	Type of Pump		
	Diesel	Tractor	Electric
Faisalabad District			
Flat charge (Rs per hour)	29.44	43.95	27.82
	(8.08)	(7.56)	(7.77)
Buyer brings fuel (Rs per hour)	32.06	n.a.	n.a.
	(5.39)		
Dir District			
Flat charge (Rs per hour)	49.23	n.a.	n.a.
	(17.54)		
Share of crop (percent)	25.00	n.a.	23.15
	(0.00)		(2.31)

Source: IFPRI survey data, 1992.
Note: Costs computed from sellers' and buyers' responses.
Figures in parentheses are standard deviations.
n.a. not applicable.

A larger sample of water sellers and purchasers under different ecological and socioeconomic conditions would be necessary to estimate the effect of these factors on the cost of private tubewell water. It does not appear, however, that the prices reported under the hourly rate or buyer-brings-fuel type of contracts represent a large profit to the tubewell owner. Thus, concerns over water sellers appropriating the value of groundwater do not seem justified, particularly in the Faisalabad area.

Sharecropping contracts for tubewell water are only applied to tomato, onion, and some maize cultivation in Dir. The standard rate is 25 percent of the crop. Three water sellers reported giving a different rate to their tenants: 20 percent as the share for the water (in addition to the share for the land), or 50 percent for the land and water combined. The use of sharecropping contracts for provision of water in Dir may reflect the greater prevalence of sharecropping for land in that area than in Faisalabad. Sharecropping contracts for water are also reported for rice and berseem crops in other regions (Chaudhry 1990; Dr. Muhammad Jameel Khan, personal communication, March 1992). The extent of crop share contracts for water may be underestimated where the landlord supplies both land and tubewell water. While tubewell irrigation may then be considered as one of the inputs which the landlord provides (such as fertilizer or plowing services), to do so masks the importance of timing and reliability of irrigation service in the overall production process.

It is noteworthy that sharecropping for tubewell water is practiced under the cultivation of crops such as tomatoes, onions, or rice, which are sensitive to moisture stress at critical periods. In sharecropping contracts, the water seller has a stake in the outcome of the crop, and a share in the risk if the water supply does not meet crop needs. Therefore, the seller has an incentive to supply tubewell water in an adequate and timely manner. This is not as critical for crops less susceptible to the timing of irrigation, or where alternate sources of irrigation are readily available. Chaudhry (1990) and Shah (1991) have suggested that, as water markets develop, there is a tendency to move toward cash contracts. If, however, sharecropping for water offers a greater incentive for sellers to provide reliable irrigation service, this type of contract may remain for water-sensitive crops. Further empirical research on the provision of tubewell water in different agroecological zones and for different crops is necessary to establish whether risk-sharing is a significant consideration in the choice of contract and timeliness of irrigation service.

5. AGRICULTURAL PRODUCTIVITY UNDER WATER MARKETS

Previous studies have shown clear productivity gains to farmers purchasing groundwater over those using only public canal or public tubewell supplies, but the gains were much less than those obtained by tubewell owners. The wheat and cotton yield increases of tubewell water purchasers (compared to those with canal water only) were half as great as the yield increases for tubewell owners in Freeman, Lowdermilk and Early's (1978) study. For rice the gap was narrower: water purchasers obtained 78 percent of the yield increases of tubewell owners (see Table 10).[20]

A study of private tubewells by WAPDA (1980, cited in World Bank 1984) found that overall cropping intensity and the proportion of area under water-consumptive crops was higher for tubewell owners than for water purchasers. There was also a yield gap between water purchasers and tubewell owners for sugarcane, rice, wheat, and vegetables (Table 11). Part of the difference in yields may be due to lower applications of irrigation water and complementary inputs such as fertilizer and insecticides by tubewell purchasers than by owners (even though tubewell purchasers used more inputs and had higher yields than non-users for almost all crops). Renfro (1982) found that the cropping intensities, the proportion of area

[20] A WAPDA (1990) study also assesses the productivity impact of purchased water. However, the yield differentials are based on farmers' assessments of what their yields would be with and without privately purchased water, and are thus not as reliable as comparisons of actual yields of farmers with and without purchased water.

Table 10--Average yields of major crops, by water source in Freeman, Lowdermilk and Early's (1978) study.

Crop	Canal Only	Public Tubewell	Purchased Tubewell	Own Tubewell
		(kg/acre)		
Wheat	672	747	784	896
Rice	522	709	784	859
Cotton	261	299	373	485

Source: D. M. Freeman, M. K. Lowdermilk, and A. C. Early. "Farm irrigation constraints and farmers' responses: Comprehensive field survey in Pakistan". (Water Management Technical Report No. 48-E, Volume V, Colorado State University, Fort Collins, CO, 1978).

Note: All tubewell water is in addition to canal supplies.

Table 11--Summary of input usage and yields for tubewell users and non-users in WAPDA study

Item	Unit	Type	Sugarcane	Rice	Gardens	Vegetable	Cotton	Wheat	Pulses	Oilseeds	Others	Total
1. Cropping pattern	% acres	O*	8	21	4	3	8	60	15	8	18	157
		P*	5	16	2	2	8	36	13	13	19	136
		Nu*	3	7	1	1	7.5	50	16	11	15	113
2. Per acre use of:												
i. Nitrogen	50 kg	O	1.5	1.5	0.5	0.9	0.5	1.0	-	0.2	0.5	
	bag	P	1.0	1.3	0.5	0.5	0.5	0.75	-	0.1	0.4	
		Nu	1.0	1.0	0.4	0.5	0.2	0.5	-	-	0.2	
ii. Phosphorus	50 kg	O	0.25	0.5	0.2	1.0	0.25	0.75	0.1	-	0.2	
	bag	P	0.2	0.5	0.2	0.5	0.1	0.6	-	-	-	
		Nu	0.2	0.4	0.1	-	0.1	0.2	0.2	-	0.1	
iii. Seed rate	Maunds	O	67	0.13	130	300	0.15	0.9	0.6	0.1	50	
	or Rs	P	71	0.12	150	300	0.14	0.8	0.6	0.1	50	
		Nu	53	0.13	150	300	0.11	0.9	0.7	0.1	50	
iv. Insecticide	Rs	O	14	11.0	50	-	25	1.0	-	-	-	
		P	18	10.5	50	-	13	-	-	-	-	
		Nu	7	11.2	50	-	17	-	-	-	-	
v. Canal water	Acre-feet	O	1.5	1.5	2.0	1.5	0.9	0.6	0.2	0.1	0.4	
		P/Nu	1.2	1.2	1.5	1.2	0.7	0.4	0.2	0.1	0.3	
vi. Tubewell delta	Acre-feet	O	2.0	2.0	1.1	0.7	0.3	0.5	-	-	0.5	
		P	1.0	1.5	1.0	0.6	-	0.3	-	-	0.3	
3. Yield per acre	Maunds	O	595.0	32.1	23.6	2450.0	1680.0	9.3	26.3	9.3	9.1	600.0
	or Rs	P	485.0	29.3	22.9	2573.0	1595.0	8.5	21.7	10.4	8.9	600.0
		Nu	315.0	21.4	18.7	2138.0	1030.0	9.2	18.5	10.8	9.7	600.0

Source: WAPDA, "Private Tubewell and Factors Affecting Current Rate of Investment," Annexure IV-3. 1980.
* O = Tubewell owner, P = Tubewell water purchaser and Nu = Non-user of tubewell water.

under water-consumptive crops, and the gross income per acre achieved by tubewell water purchasers more closely approximated that of farmers who only received canal water than that of tubewell owners, even though their cash and labor inputs were virtually as high as those of tubewell owners (Table 12).

In part, water buyers may have lower cropping intensities and yields than tubewell owners because buyers choose to use less water due to the cost of purchased tubewell water. However, the price of water for tubewell purchasers in the IFPRI sample was not much greater than the cost to tubewell owners (except for owners of electric pumpsets with fixed electricity charges, who face a very low marginal cost and therefore have an incentive to pump as much water as can be used). Whether tubewell water purchasers use less groundwater based on an input allocation decision or supply constraints is unclear. As discussed below, there are numerous occasions on which tubewell water is not available to water buyers at any cost, despite their demand for it. The lower reliability of purchased tubewell water compared to owned tubewell water is likely to be a major contributor to any yield or income gap between tubewell owners and water purchasers. Renfro (1982:83) concludes that, in comparison with water purchasers, "obviously actual sampled tubewell owners can exert more control over water supplies with favorable impacts on productivity."

The differences in cropping pattern between tubewell owners, water purchasers, and non-users of tubewell water are not as clear in the IFPRI sample

villages as in the WAPDA (1980) and Renfro (1982) studies. Table 13 examines the cropping pattern in Faisalabad and Dir districts by source of irrigation.

Table 12--Input use and agricultural productivity in Renfro's (1982) study

	Canal Water Only		Tubewell Buyers		Tubewell Owners	Total
Gross crop income	3018		3475		4659	3297
(Rs/acre)	(1081)	*	(1632)	*	(2029)	(1453)
Canal water use/	26.3		26.2		25.2	26.0
acre (acre minutes)	(9.5)		(5.6)		(6.7)	(9.2)
Tubewell water use/	0.0		14.2		31.4	7.9
acre (acre minutes)	(0.0)	*	(13.3)	*	(21.9)	(14.9)
Cash input expenditure	309		385		388	344
(Rs/acre)	(156)		(158)		(86)	(198)
Labor use	73.8		76.2		75.5	74.0
(mandays/acre)	(37.8)		(35.4)		(46.4)	(37.3)
Cropping intensity	160		168		184	164
(percent)	(25)		(28)		(23)	(26)
Percent high water	35		36		45	36
using crops	(17)		(22)		(20)	(19)
Sample size	69		50		10	129

Source: R. Z. H. Renfro. "Economics of local control of irrigation water in Pakistan: A pilot study". (Ph. D. diss., Colorado State University, Fort Collins, CO, 1982).
Note: Figures in parentheses are standard deviations.
* Difference between categories significant at 0.05 probability level.

In Faisalabad, the average total cropping intensity for tubewell owners, water purchasers and non-tubewell users is 176 percent. In Jaranwala, where there is no alternative irrigation source, tubewell water purchasers have a slightly higher cropping intensity than owners (182 compared to 176 percent--though the differences are not significant). In Dir, tubewell owners have the highest average cropping intensity (197 percent), followed by non-tubewell users (171 percent) and water purchasers (167 percent).

The proportion of area under individual crops shows no clear pattern across the sample. For example, tubewell owners in Faisalabad plant more fodder, wheat, and sugarcane than other crops, while wheat is the major crop for water purchasers, followed by fodder and sugarcane. Non-tubewell users in Faisalabad plant the greatest proportion of their land in sugarcane, an extremely water-consumptive crop, followed by wheat. In Jaranwala, both tubewell owners and water purchasers plant a greater amount of fodder than do farmers in other Faisalabad villages. In Dir, tubewell owners plant 62 percent of their land in fodder, while water purchasers (who are largely tenants) plant only 5 percent and non-tubewell users plant 21 percent. Dir farmers, particularly tubewell owners and water purchasers, also plant a large area under wheat and maize, as well as substantial area under tomato and onion. Further analysis of the net returns to total farm operations would be necessary to understand the relationship between crop choice and type of irrigation.

Table 13--Cropping pattern by access to tubewell water, Faisalabad and Dir Districts

	Percent of Total Acres Under												Total Cropping Intensity
	Wheat	Rice	Sugarcane	Fodder	Maize	Pulses	Cotton	Oilseeds	Tomato	Onion	Other Vegetables	Other Crops	
Faisalabad - Total													
Tubewell owner	59	2	30	70	1	0	4	0	0	0	8	0	175
(n=22)	(24)	(6)	(31)	(44)	(4)	(0)	(11)	(0)	(0)	(0)	(21)	(0)	(22)
Tubewell water buyer	71	2	25	49	8	0	15	0	0	0	5	0	176
(n=46)	(19)	(7)	(24)	(31)	(18)	(0)	(20)	(1)	(0)	(0)	(17)	(1)	(27)
Non-tubewell user	48	1	68	42	8	1	5	1	0	0	3	0	177
(n=24)	(30)	(4)	(47)	(47)	(11)	(5)	(10)	(4)	(0)	(0)	(14)	(0)	(37)
Jaranwala													
Tubewell owner	57	4	26	88	0	0	0	0	0	0	0	0	176
(n=15)	(28)	(7)	(36)	(40)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(21)
Tubewell water buyer	71	7	26	76	0	0	0	0	0	0	0	2	182
(n=5)	(22)	(15)	(43)	(34)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(3)	(30)
Faisalabad other Villages													
Tubewell owner	61	0	37	32	3	0	14	0	0	0	26	0	173
(n=7)	(13)	(0)	(20)	(18)	(7)	(1)	(15)	(0)	(0)	(0)	(33)	(0)	(25)
Tubewell water buyer	71	2	24	46	9	0	17	0	0	0	6	0	175
(n=41)	(19)	(5)	(21)	(30)	(19)	(0)	(21)	(1)	(0)	(0)	(18)	(0)	(27)
Non-tubewell user	48	1	68	42	8	1	5	1	0	0	3	0	177
(n=24)	(30)	(4)	(47)	(47)	(11)	(5)	(10)	(4)	(0)	(0)	(14)	(0)	(37)
Dir - All Villages													
Tubewell owner	50	0	0	62	49	1	0	0	17	19	0	0	197
(n=4)	(41)	(0)	(0)	(93)	(56)	(2)	(0)	(0)	(33)	(32)	(0)	(0)	(7)
Tubewell water buyer	44	1	0	5	40	5	0	4	30	23	5	11	167
(n=8)	(25)	(5)	(0)	(8)	(40)	(10)	(0)	(9)	(33)	(35)	(10)	(13)	(41)
Non-tubewell user	64	3	0	21	48	4	0	2	16	8	0	6	171
(n=73)	(35)	(14)	(0)	(38)	(38)	(10)	(0)	(7)	(26)	(18)	(1)	(18)	(42)

Source: IFPRI survey data, 1990-1992.
Note: Figures in parentheses are standard deviations.

In order to examine the impact of different sources of irrigation on yields, a production function was estimated using plot-level data for the 1990-91 agricultural year. Due to limited degrees of freedom for other crops in the sample, this equation was estimated for wheat only, a staple crop grown by nearly all farmers in both Faisalabad and Dir. Table 14 shows the results of this estimation, using linear regression.[21] Seeding rate, total fertilizer applications (defined as kilograms of elemental Nitrogen and Phosphorous per acre), total labor inputs, soil characteristics of pH, potassium, phosphorous, and salinity are included in the model along with the number of irrigation applications from own tubewells, purchased groundwater, and canal water. Soil pH has been transformed to degree of alkalinity, a variable computed by subtracting 7 from to the original pH value.[22] Salinity is represented by a dummy variable indicating if measured electrical conductivity levels are greater than or equal to 4 millimhos per centimeter, the threshold level for average crop tolerance of salinity.

[21] Alternative functional forms, such as Cobb-Douglas and log-linear, were tested, but did not fit the data as well as linear regression. The large number of cases with values of 0 for one or more of the independent variables, notably the irrigation inputs, may account for the poor fit of the Cob-Douglas equation. Quadratic and interaction terms were tested, but found not significant, and are therefore not included in the model.

[22] Original pH on sample plots ranges from 7.0 (neutral) to 8.5 (alkaline).

Table 14--Effect of irrigation applications on plot-level wheat yields in Faisalabad and Dir Districts

Independent Variables	Coefficient	Standard Error	T Statistic	Variable Mean
Seeding rate (kg/acre)	3.60 **	1.82	1.98	40.93
Fertilizer (N + P kg/acre)	4.67 **	.73	6.09	47.12
Labor (person-days/acre)	1.89 *	1.12	1.68	27.86
Degree of alkalinity (adjusted pH)	253.54 **	69.20	3.66	0.62[a]
Soil Potassium (ppm/acre)	1.25 **	.38	3.32	128.14
Soil Phosphorous (ppm/acre)	-4.50	4.82	-.93	10.07
Soil salinity dummy	-44.61	68.99	-.65	.13[b]
Canal irrigations	31.14 **	9.00	3.46	2.53
Purchased tubewell irrigations	44.58 **	16.66	2.68	.62
Own tubewell irrigations	48.31 **	18.45	2.62	.50
Constant	-63.16	112.20	-.56	

Adjusted R Square = 0.31 **
Number of observations = 263.0

Source: IFPRI survey data, 1990-1992.
a Degree of alkalinity = soil pH - 7.0.
b Variable equals 1 if electrical conductivity $\geq$ 4 mmhos/cm, 0 otherwise.
** Significant at 5 percent probability level
* Significant at 10 percent probability level

The seeding rate and amount of nitrogen and phosphorous fertilizer have a strong positive effect on wheat yields.[23] Total labor inputs, including family, exchange, permanent hired, and casual hired labor are also associated with higher yields. The level of potassium in the soil and degree of soil alkalinity are positively associated with yields. Higher pH values influence yields because slightly alkaline soils (those with a pH above 7.0) are characterized by greater nitrogen, phosphorous, and potassium availability. The

[23] A single variable for the sum of nitrogen and phosphorous fertilizer is used because the levels of these two inputs are multicollinear. If N and P are included as separate variables in the model, both have significant coefficients of approximately the same magnitude as the total fertilizer coefficient (4.4) in the final model.

coefficients for other soil characteristics--phosphorous content and salinity are not significant.

The lack of a significant effect of electrical conductivity on wheat yields is important because in areas of tubewell irrigation, secondary soil salinity induced by large amounts of groundwater use is a potential concern (Murray-Rust and Vander Velde 1992). Present levels of salinity, which average 0.8 millimhos per centimeter in Dir and 3.2 millimhos per centimeter in the Faisalabad study area do not appear problematic, but higher levels may reduce productivity.

After controlling for fertilizer input and soil fertility, all three types of irrigation inputs had a significant positive effect on wheat yields. But the magnitude of the coefficients indicates that each irrigation application from own tubewells has the highest impact on yield, followed by purchased groundwater and canal applications.

The number of applications is an imperfect indicator of irrigation, because it does not control for the volume of water used per application (though the area of crop irrigated is controlled for), nor for timing of applications. The volume of water per application is usually lower for tubewell than for canal applications, and therefore would not explain the higher productivity of groundwater irrigation. However, farmers have relatively little control over timing under warabandi rotations of canal systems. Tubewell water can be adjusted to the crop needs and growing cycle, and therefore have a greater impact on production.

The estimates of productivity of tubewell irrigation, particularly from own tubewells, are influenced by a number of tubewells in Jaranwala, a village within the formal command area of the canal system, but which actually receives little or no canal water (except through groundwater recharge). While it may be argued that this is not representative, it is precisely in such areas that tubewell irrigation is likely to be most important in agricultural production.

This production function, which focuses on seeds, fertilizer, labor, soil fertility, and irrigation, does not include all influences on productivity, such as weather, seed variety and quality, human and physical capital, and even water quality. There are also selection processes underlying farmers' decisions to invest in tubewells and to purchase tubewell water, in addition to factors influencing whether farmers have access to canal water, which could be included in the model. Furthermore, these relationships may differ under other agroecological conditions, such as areas with significant salinity problems. However, these results show that irrigation, and especially tubewell irrigation, has a strong impact on yields among sample farmers in Faisalabad and Dir Districts. At the same time, they point to a productivity gap between the effect of own tubewell water, over which farmers have considerable control, and purchased tubewell water, over which farmers have less control. The following section examines factors which affect the reliability of purchased tubewell water, in order to identify ways to improve the performance of water markets.

6. RELIABILITY OF IRRIGATION SERVICE

The productivity of irrigated agriculture is not determined solely by the amount of irrigation water supplied. The timeliness and reliability of water supplies is also critical. Timing waterings to meet crop evapotranspirative demand has a direct impact on yield, while the confidence farmers have in their water supply can affect their crop choice, level of fertilizer and labor use, and the application of other inputs. Few studies of water markets have addressed the timeliness and reliability of purchased irrigation services, especially because they are difficult to quantify and measure. However, availability of water throughout the season, especially at critical times, provides one indicator of irrigation service.

Because tubewell water is not tied to a fixed warabandi rotation schedule, it is easier to match tubewell irrigations to crop needs, in order to provide more frequent irrigations during periods of peak demand, if necessary. Tubewell water is also available throughout the year, except during periods of mechanical breakdown. In the IFPRI sample, tubewell owners reported that pump or engine failures made groundwater unavailable for an average of 2 weeks per season in Faisalabad, and 1 week per season in Dir. This compares favorably with the reported unavailability of canal water for an average of 4 weeks per season in Faisalabad and 5 weeks per season in Dir.

Although the reliability of irrigation service under private tubewells is generally higher than under public sources such as canals and government tubewells, it is likely to be lower for water purchasers than for farmers with their own wells because tubewell owners sell surplus water after meeting the needs of their own crops. Thus, the deficits created by shortages of groundwater or energy supplies are not shared equally between owner and purchaser, but rather reduce groundwater availability to purchasers first. Such groundwater shortages compound groundwater unavailability due to mechanical failure of pumps, the latter affecting both owners and purchasers.

Tubewell water sellers and purchasers in the IFPRI sample were asked whether water was always available when requested, as an indicator of reliability. Farmers responded that water is most likely to be unavailable during periods of electricity shortage or load shedding, and during periods of peak water demand. Not surprisingly, the water purchasers were more likely to identify problems with water availability than were the water sellers (Table 15). Over a fourth of Faisalabad water buyers reported that they were unable to purchase water to meet crop needs during times of load shedding, although no sellers reported being unable to sell because of load shedding. Times of peak demand are more problematic: nearly a fourth of all sellers and over half of all buyers reported that purchased tubewell water was not always available when needed during such periods.

Table 15--Reported availability of purchased tubewell water

Purchased Tubewell Water Unavailable During:	Faisalabad		Dir		Total	
	Sellers Reporting	Buyers Reporting	Sellers Reporting	Buyers Reporting	Sellers Reporting	Buyers Reporting
Electricity load shedding	0 (0.0)	22 (26.5)	0 (0.0)	0 (0.0)	0 (0.0)	22 (22.4)
Peak demand seasons	1 (14.3)	54 (65.1)	2 (33.3)	1 (6.6)	3 (23.1)	55 (56.1)
Total sample size	7	83	6	15	13	98

Source: IFPRI survey data, 1992.
Note: Figures in parentheses are percentages.

What influences the reliability of purchased irrigation water? Three factors can be hypothesized to have an effect: type of tubewell, characteristics of the buyer, and the relationship between seller and buyer. Electric tubewells are more susceptible to power outages, and are therefore likely to be less reliable. Larger-capacity tubewells and those which draw water from deeper levels are hypothesized to be more reliable. Buyers with higher social status, indicated by land ownership and age, are also hypothesized to have more reliable access to purchased tubewell water. If social ties influence reliability of water markets, farmers who buy water from close relatives or their landlords would be expected to receive more reliable irrigation service.

A logistic regression model has been used to test these hypotheses, using buyers' reported availability of tubewell water whenever needed as an indicator of reliability. Dummy variables for Jaranwala village in Faisalabad and for Dir district are included to control for agroecological differences between these areas and the rest of the sample (most notably the differential availability of canal irrigation).

Results of the logit model are given in Table 16. As predicted, electric tubewells are significantly less reliable than those with diesel or tractor-powered lifts.[24] Larger-diameter tubewells were significantly more reliable than smaller ones, but deeper tubewells do not provide more reliable irrigation for purchasers--indeed, the coefficient is negative, though not significant. Deeper tubewells may be located in groundwater-scarce areas, and therefore provide less reliable supplies to purchasers.

---

[24] In an alternate specification of the model, the difference was found between diesel and tractor tubewells was tested and found not significant.

Table 16--Results of logistic regression model for reliability of purchased tubewell water

Independent Variables	Units	Coefficient	T Ratio	Wald Statistic
Electric tubewell	dummy	-2.189 **	-2.934	8.617
Tubewell diameter	inches	1.267 **	2.368	5.587
Tubewell depth	feet	-.026	-1.245	1.553
Size of land ownership	acres	.072 **	1.986	3.949
Age of household head	years	.045 *	1.844	3.398
Buy from close relative	dummy	.855	.866	.750
Buy from landlord	dummy	10.613	.435	.189
Jaranwala village	dummy	.668	.726	.527
Dir district	dummy	4.209 **	2.397	5.745
Constant		-5.929 *	-1.838	3.378

Model Chi-Square = 58.2 ** with 9 degrees of freedom
Number of observations = 96.0

Classification Table for Reliability of Purchased Tubewell Water

	Predicted		Percent
	NOT RELIABLE	RELIABLE	Correct
Observed			
NOT RELIABLE	49	6	89.1
RELIABLE	9	32	78.5
			Overall 84.4

Source: IFPRI survey data, 1992.
** Significant at 5 percent probability level
* Significant at 10 percent probability level

The amount of land owned has a significant and positive effect on reliability, suggesting that water sellers are less likely to deny requests for water from larger land-owners than from small landowners or landless tenant cultivators. This is due to the influence of the land owners, not the size of farm operated. An alternate specification of the model with operational holding, rather than land ownership, showed no significant coefficient for size of holding.[25] The age of purchasers' head of household, another indicator of status, has a positive effect on reliability. The model does not show kinship or landlord-tenant relationships between water buyer and seller to have a significant effect on reliability of access to groundwater. Jaranwala village does not differ significantly from other areas in reliability of purchased tubewell water, but buyers in Dir district reported significantly more reliable access to groundwater. This is somewhat surprising because irrigation is less available in Dir than in the canal-irrigated areas of Faisalabad, and therefore demand for groundwater would be expected to be higher. However, rainfall is higher in Dir, and therefore groundwater may be more readily available to those farmers needing supplemental irrigation.

While buyers' reported problems with unavailability of purchased groundwater is an imperfect indicator of reliability, this model points to important sources of problems in groundwater markets. Purchasers are more likely to receive insufficient groundwater if they buy from small-capacity, electric-powered tubewells; if they are young and own little or no land; and if they live in Faisalabad District. Improving the reliability of electric power or switching to diesel pumps are the most readily identifiable interventions to improve reliability of groundwater markets (as well as reliability of water for well owners). Both of these options are, however, expensive. Identifying the factors which lead to lower reliability in Faisalabad than in Dir requires further study.

[25] Both ownership and operational holding size could not be included because of multicollinearity problems.

Although land ownership and age have strong influences on reliability, they do not appear to point to policy interventions that can improve reliability. Improving the reliability of irrigation by increasing the land ownership and age of water-purchasing households is not feasible, or even desirable. However, it may be possible to raise the status of purchasers relative to water sellers by encouraging smaller farmers to purchase tubewells. This study does not have data on both the sellers' and buyers' characteristics for each relationship, but it is possible that farmers with less land will provide more reliable service, both because there is less of a status gap between them and the purchasers, and because tubewell owners with less land will not need as much water to meet irrigation needs on their own fields, and thus have surplus water available for sale.

7. RESEARCH AND POLICY MEASURES FOR WATER MARKET DEVELOPMENT

Water markets are largely autonomous, indigenous institutions which function--and are likely to continue functioning--without a great deal of official intervention. What type of attention, if any, should the government, researchers, and other agencies pay to water markets? This final section highlights policy instruments and remaining research questions pertaining to water market development.

First, understanding the role water markets play in mediating access to and control over groundwater resources can assist tubewell development programs in serving a larger number of farmers. This study indicates that water markets improve the equity of groundwater use by increasing the access of small farmers, tenants, and younger households who are least likely to own tubewells. Thus, neither public tubewells nor ownership of tubewells by all farmers are required to ensure widespread use of groundwater in areas where water markets operate.

However, the study also demonstrates that water markets do not operate in all areas, raising the question of which factors influence the activity of water markets. Conditions that affect the amount of groundwater available for sale include the number of tubewells in an area, the proportion of tubewell owners willing to sell water, and the nature of the underlying groundwater resource. Because, with current technology, water cannot be transported over large distances, wells must be available within close proximity to buyers' fields for groundwater markets to operate. Chambers, Saxena and Shah (1989) suggest that a higher density of tubewells fosters the development of competitive water markets. Thus, programs which assist private tubewell development, especially in areas of adequate, good-quality groundwater, are also likely to assist water market development.

Making information about water markets more widely available both to individuals and groups of farmers may also stimulate further investment in tubewells. For example, knowledge of the potential for groundwater sales in a given area, different credit options for investment and contractual arrangements for water sales could be an important decision-making tool for potential investors. This information could be gathered and disseminated by local groups, non-governmental organizations or projects such as the Private Tubewell Development Project.

Due to the small sample of tubewell owners, this study was not able to determine factors affecting which tubewell owners will sell water. Possible factors influencing the decision to sell include the size and location of tubewell owners' land holdings and their cropping patterns, as well as tubewell technology and energy costs. Further research on this topic, as well as on the nature of the specific transactions occurring between buyers and sellers, would be useful in stimulating water markets.

As noted above, large farmers are most likely to own tubewells, while small farmers are more likely to depend on water purchases, and consequently face less reliable access to groundwater. However, larger farmers are also able to use more of their tubewell water on their own land. Tubewell owners with smaller holdings may be more likely to sell water, because they have surplus capacity beyond what is needed to irrigate their holdings. Those with less land may also rely more on water sales to recoup their investment in the well and pumpset, and hence be more concerned with providing reliable irrigation services to others. Thus, targeting farmers with smaller holdings for tubewell purchase could increase participation in water markets and the reliability of tubewell water deliveries for buyers.

Credit and other types of assistance for tubewell investment are available to small farmers (though not to landless tenants). The Agricultural Development Bank requires ownership of only 3 acres in a consolidated area to receive credit for tubewells, and has a lower requirement of equity contribution for smaller farmers. However, analysis by Malik, Broca, and Gill (1992) indicates that institutional credit does not reach many small farmer households. Efforts are needed to ensure that smallholders actually receive assistance. These efforts can include simplifying application forms and procedures for receiving credit, electricity connections, and technical assistance.

Tubewell technology and energy costs are also likely to affect owners' willingness to sell. Large-capacity pumps can deliver water to a wider area (though smaller pumps with lower investment and operations costs may be preferable for small farmers). Electric-powered pumps generally have lower operation and maintenance costs compared to diesel and tractor-powered lifts. A flat rate power tariff structure, under which the tubewell owner pays a monthly fee per horsepower of the motor regardless of the quantity of electricity consumed, reduces the marginal cost of pumping to virtually zero, and therefore creates an incentive to sell as much water as possible (Shah 1992). However, a high fixed monthly cost of electricity may also be a deterrent to investment by small farmers who are unsure of their ability to sell enough water throughout the year. WAPDA calculations for the Private Tubewell Development Project indicate that the flat rate tariff is the cheapest source of energy for pumping if farmers use an average 20 percent of pump capacity. But, given the fluctuations in demand for tubewell water (both on owners' farms and through water markets) maintaining an average 20 percent of capacity throughout the year is often difficult.

A major drawback to electric-powered tubewells is their susceptibility to fluctuations in power supply. If power is not available for much of the time, it does not matter if the marginal cost of energy is nearly zero. What is more relevant to tubewell owners' decisions to sell water is the opportunity cost of the water which could be pumped and applied to their own fields. As long as tubewell owners only sell surplus water above their own needs, rather than selling water as an enterprise in itself, shortages of tubewell water due to load shedding will be disproportionately borne by the purchasers rather than by well owners. Rationing and uncertainty of power supply translates into rationing of groundwater available for sale. Diesel may be relatively more expensive, but under present conditions it is a more reliable source of energy than electricity. As noted above, purchasers from electric tubewells report more problems than those who buy from diesel tubewells. Thus, extending electricity grids and making it easier for farmers to obtain connections for tubewells can assist in development of water markets, but only if the power supply is also reliable. Further study is needed to determine which factors, besides improved electricity supplies, can increase the reliability of groundwater irrigation services, particularly for small farmers.

Joint investment in a well by a group of farmers may be another viable means of making groundwater available to a large number of farmers, including small farmers and tenants. This study found 15 of 18 wells to be jointly owned by groups of 5 to 12 farmers in Jaranwala village, where there is heavy dependence on groundwater. Environmental differences between this village and other study areas do not allow direct comparison of the costs and quality of irrigation service between jointly-owned wells and water markets from individually-owned wells, but further research could address the relative merits of each system.[26] There are likely to be difficulties in organizing and maintaining a group of joint owners, but there may also be substantial benefits in terms of irrigation service and risk-sharing. Joint ownership may also allow optimal location of wells in terms of tapping good quality groundwater and being able to serve the maximum number of farmers (such as near the head of a watercourse). Efforts to establish well ownership in conjunction with water users' associations (as in some areas under the On Farm Water Management Program or the PATA project in NWFP) merit further examination.

[26] Jointly-owned wells are not incompatible with water markets (as seen in the Jaranwala study village). Water may be available to non-owners, though usually at a different cost than to owners.

Many of the credit and subsidy programs to encourage private tubewell development have focussed on wells and pumping equipment. The contribution of lined channels and pipes to the development of groundwater irrigation in general, and water markets in particular, has been largely overlooked. Lining delivery channels to reduce water losses extends the effective command area of tubewells. At present there is little private investment in lined conveyance or pipes for tubewell water in Pakistan, but pukka watercourses are important. In the IFPRI sample, lined watercourses in canal command areas allowed water to be conveyed over distances of 1 to 3 kilometers from the tubewell to the purchaser's plot. The watercourse rehabilitation and lining done under the On Farm Water Management and related projects can, therefore, not only contribute to canal irrigation performance, but also provide infrastructure to assist the development of water markets. In many areas, lining is no longer cost-effective in terms of reducing canal water losses. But if savings of relatively more expensive (and high-value) tubewell water are included, watercourse lining may be more attractive. Using lined watercourses for tubewell water can also increase farmers' incentives to maintain the watercourses. However, regulations (especially under the Canal and Drainage Act) should be re-examined to see if they pose unnecessary restrictions on the use of watercourses for tubewell water.

Because of their importance in expanding access to and use of groundwater irrigation, it is important to improve our understanding of water markets and their linkages to crop choice, agricultural productivity and resource sustainability. Results of this and other studies demonstrate that purchased irrigation makes a significant contribution to productivity, but also indicate a productivity gap between own and purchased groundwater. The greater control of irrigation afforded by tubewell ownership is likely to be a major factor in this, but further study is needed to assess how this affects overall cropping patterns and farm incomes.

Much of the empirical work on water markets in Pakistan to date has been in relatively favorable conditions: fresh groundwater areas, and areas where recharge equals or exceeds groundwater withdrawals. The incentive and managerial problems of getting farmers to pump and purchase groundwater where it is so saline that it has to be mixed with canal flows are considerable, and may require continued state intervention through public tubewells. Where waterlogging (but not salinity) is a problem, developing water markets can help to control rising water tables. In areas where groundwater is in scarce supply, water markets may encourage overexploitation of the resource, and thus need to be monitored and, if possible, regulated. If tubewell owners reserve first use of groundwater to meet their own crop needs before selling water to others, groundwater scarcity is likely to exacerbate problems of unreliability for water purchasers. Research is needed on how water markets work in these less favorable environments, and to identify policy interventions that are appropriate under each set of circumstances.

REFERENCES

Adams, R. H. 1992. The effects of internal and international migration and remittances on income distribution in rural Pakistan. International Food Policy Research Institute, Washington, D.C.

Aklilu, P, and A. Hussain. 1992. Pakistan: Public and private irrigation development. In *Developing and improving irrigation and drainage systems,* ed. G. Le Moigne, S. Barghouti, and L. Garbus, 23-34. World Bank Technical Paper No. 178. Washington, D.C.: World Bank.

Alderman, H., and M. Garcia. 1991. Poverty, household food security and nutrition in rural Pakistan. International Food Policy Research Institute, Washington, DC.

Athreya, V. B. 1991. Rapporteur's report on land and water markets. *Indian Journal of Agricultural Economics* 46 (3): 492-497.

Bajwa, A. R., and C. B. Ahmad. 1991. *Trading of canal and tubewell water for irrigation purposes*. Lahore: Watercourse Management and Evaluation Directorate, P&I, WAPDA.

Barah, B. C. 1992. Emergence of groundwater market and ecological impact on the drought prone areas. Paper presented at the International Conference on "Prospects of Chinese Agricultural Development in the 1990s", August 20-25 at Beijing China organized by the American Association of Agricultural Economics in cooperation with the China's Agricultural Economics Association.

Bardhan, P. K. 1984. *Land, labor, and rural poverty: Essays in development economics*. Delhi: Oxford University Press.

Bardhan, P. K., and T. N. Srinivasan. 1971. Cropsharing tenancy in agriculture: A theoretical and empirical analysis. *The American Economic Review* 61: 48-64.

Byrnes, K. J. 1992. *Water user's associations in World Bank assisted irrigation projects in Pakistan*. World Bank Technical Paper Number 173. Washington, DC: World Bank.

Chambers, R., N. C. Saxena, and T. Shah. 1989. *To the hands of the poor: Water and trees.* New Delhi, India: Oxford and IBH Publishing Co. Pvt. Ltd.

Chaudhary, M. A., and R. A. Young. 1989. Economic impacts of alternative irrigation water allocation institutions: Pakistan's warabandi system. In *Social, economic, and institutional issues in third world irrigation management,* ed. R. K. Sampath and R. A. Young, 395-410. Boulder, Colorado: Westview Press.

____. 1990. Privatizing public irrigation tubewells in Pakistan: An appraisal of alternatives. *The Pakistan Development Review* 29 (1): 33-58.

Chaudhry, M. J. 1990. The adoption of tubewell technology in Pakistan. *The Pakistan Development Review* 29 (3-4): 291-303.

Dhawan, B. D. 1991. Groundwater Markets: A critique. Comments prepared for International Society of Agricultural Economic meetings.

Freeman, D. M., M. K. Lowdermilk, and A. C. Early. 1978. *Farm irrigation constraints and farmers' responses: Comprehensive field survey in Pakistan.* Water Management Technical Report No. 48-E, Volume V. Fort Collins: Colorado State University.

Gill, Z. A., and R. K. Sampath. 1992. Inequality in irrigation distribution in Pakistan. *The Pakistan Development Review* 31: 1 (Spring 1992) 75-100.

Hussain, R. Z., and R. A. Young. 1985. Estimates of the economic value productivity of irrigation water in Pakistan from farm surveys. *Water Resources Bulletin* 21 (6): 1021-1027.

Hussain, T. 1992. Dynamics and integration of the land and water markets. Paper presented at the workshop on Impact of Technological Change in Wheat, 1965-1990.

Johnson, R. 1989. *Private tube well development in Pakistan's Punjab: Review of past public programs/policies and relevant research*. Colombo, Sri Lanka: International Irrigation Management Institute.

Kolavalli, S. 1989. Comments at colloquium on "How to reach the poor through groundwater, irrigation," organized by the World Bank, April 12-14, Washington, D.C.

Kolavalli, S., and L. K. Atheeq. 1990. Groundwater utilization in two villages in West Bengal. Centre for Management in Agriculture, Indian Institute of Management, Ahmedabad, India.

Kolavalli, S., and D. L. Chicoine. 1989. Groundwater markets in Gujarat, India. *Water Resources Development* 5 (1): 38-44.

Kolavalli, S., A. H. Kalro, and V. N. Asopa. 1989. *Issues in development and management of groundwater resources in East Uttar Pradesh*. Ahmedabad, India: Centre for Management in Agriculture, Indian Institute of Management.

Kolavalli, S., G. Naik, and A. H. Kalro. 1992. Utilization of groundwater in East Uttar Pradesh. Centre for Management in Agriculture, Indian Institute of Management, Ahmedabad, India.

Kuper, M. and P. Strosser. 1992. The appropriateness of canal water supplies: The response of the farmers. A case study in the Fordwah/Eastern Sadiqia Area, Punjab, Pakistan. IIMI, Lahore.

Malik, S., S. Broca, and M. Gill. 1992. Credit constraints and household borrowing behavior: Impact on household consumption and fertilizer use in selected areas of rural Pakistan. International Food Policy Research Institute, Washington, DC.

Murray-Rust, D. H., and E. J. Vander Velde. 1992. Conjunctive Use of canal and groundwater in Punjab, Pakistan: Management and policy options. Paper presented at The Eighth Internal Program Review, November 30 to December 2, 1992. International Irrigation Management Institute, Colombo, Sri Lanka.

NESPAK (National Engineering Services Pakistan). 1991. Contribution of private tubewells in the development of water potential. *Final Report*. (Islamabad: Government of Pakistan, Ministry of Planning and Development, Planning and Development Division).

Pakistan, Ministry of Food Agriculture and Cooperatives. 1991. *Agricultural statistics of Pakistan 1990-91.* Islamabad,: Government of Pakistan.

Pant, N. 1991a *Development of ground water markets in Eastern Uttar Pradesh.* Prepared for Indo-Dutch Tubewell Project. Lucknow, India: Centre for Development Studies.

____. 1991b. Groundwater issues in eastern India. In *Future directions for Indian irrigation: Research and policy issues*, ed. R. Meinzen-Dick and M. Svendsen 254-286, Washington, D.C.: International Food Policy Research Institute.

____. 1992. *New trend in Indian irrigation.* New Delhi, India: Ashish Publishing House.

Pinckney, T. C. 1989. *The demand for public storage of wheat in Pakistan.* IFPRI Research Report 77. Washington, D.C.: International Food Policy Research Institute.

Punjab, Bureau of Statistics. 1988. *Punjab development statistics*. Lahore: Government of Punjab.

Rana, Z. H., and R. Shafiq-ur-Rehman. (n. d.). *Water supply, distribution policy and economic value of irrigation water in the Indus Basin*. Islamabad: Pakistan Association of Agricultural Social Scientists.

Renfro, R. Z. H. 1982. Economics of local control of irrigation water in Pakistan: A pilot study. Colorado State University, Fort Collins, Colorado.

Renfro, R. Z. H., and E. W. Sparling. 1986. Private tubewell and canal water trade on Pakistan Punjab watercourses. In *Irrigation investment, technology, and management strategies for development*, ed. K. W. Easter, 193-210. Boulder, Colorado: Westview Press.

Rosegrant, M. W., and H. P. Binswanger. 1994. Forthcoming. Markets in tradable water rights: Potential for efficiency gains in developing-country irrigation. *World Development.*

Saleth, R. M. 1991. Factors affecting farmers' decision to buy groundwater: Empirical evidence from the Indo-Gangetic Region. *Indian Journal of Agricultural Economics* 46 (3): 349-354.

Shah, T. 1985. *Transforming ground water markets into powerful instruments of small farmer development: Lessons from the Punjab, Uttar Pradesh and Gujarat.* Network paper 11d. London: Overseas Development Institute.

____. 1989. *Efficiency and equity impacts of groundwater markets: A review of issues, evidence and policies.* Anand, India: Institute of Rural Management.

____. 1991. Water markets and irrigation development in India. *Indian Journal of Agricultural Economics* 46 (3): 335-348

____. 1992. Sustainable development of groundwater resource: Lessons from Junagadh District. *Economic and Political Weekly* 27: 515-520.

Shah, T., and K. V. Raju. 1988. Ground water markets and small farmer development. *Economic and Political Weekly*. 23(13): A23-A28.

Shankar, K. 1992a. *Dynamics of groundwater irrigation.* New Delhi: Segment Books.

____. 1992b. Water market in eastern Uttar Pradesh. *Economic and Political Weekly.* 931-933.

Sims, H. 1988. *Political regimes, public policy and economic development: Agricultural performance and rural change in two Punjabs.* New Delhi, India: Sage Publications.

WAPDA (Water and Power Development Authority). 1980. *Private tubewells and factors affecting current rate of investment*. Lahore: WAPDA, Economic Research Section, Planning and Development Division.

____. 1990. *Trading of canal and tubewell water for irrigation purposes.* Lahore: Watercourse Monitoring and Evaluation Dte. P & I Organization, Planning Division.

____. 1982. *Revised action program for irrigated agriculture*. *Final Report.* Lahore, Pakistan.

Wood G. D., and R. Palmer-Jones. 1990. *The water sellers: A cooperative venture by the rural poor.* West Hartford, Connecticut: Kumarian Press.

World Bank. 1984. Public and private tubewell performance: Emerging issues and options. *Pakistan Subsector Report*. Washington, D.C.

Young, R. A. 1987. Market versus non-market methods of allocating irrigation water: A review of the issues. In *Water and water policy in world food supplies (conference proceedings),* ed. W. R. Jordan. College Station, Texas: Texas A and M University Press.

Appendix Table 1--Participation in tubewell water market in Punjab mixed cropping zone, by size of land ownership

	Total Land Ownership						
	<1 acre	1-5 acres	6-12 acres	13-25 acres	26-50 acres	>50 acres	Total
Tubewell owner	0 (0.0)	15 (44.1)	17 (48.6)	33 (91.7)	12 (70.6)	12 (85.7)	89 (65.0)
Tubewell water buyer	1 (100.0)	11 (32.4)	9 (25.7)	2 (5.6)	4 (23.5)	1 (7.1)	28 (20.4)
Total sample size	1	34	35	36	17	14	137

Source: National Input Output survey data, Agricultural University of Faisalabad, 1991/92.

Note: Figures in parentheses are percentage of farmers in each size category who own tubewell or purchase tubewell water.

List of EPTD Discussion Papers

01 *Sustainable Agricultural Development Strategies in Fragile Lands*, by Sara J. Scherr and Peter B. R. Hazell, June 1994.

02 *Confronting the Environmental Consequences of the Green Revolution in Asia*, by Prabhu L. Pingali and Mark W. Rosegrant, August 1994.

03 *Infrastructure and Technology Constraints to Agricultural Development in the Humid and Subhumid Tropics of Africa*, by Dunstan S. C. Spencer, August 1994.